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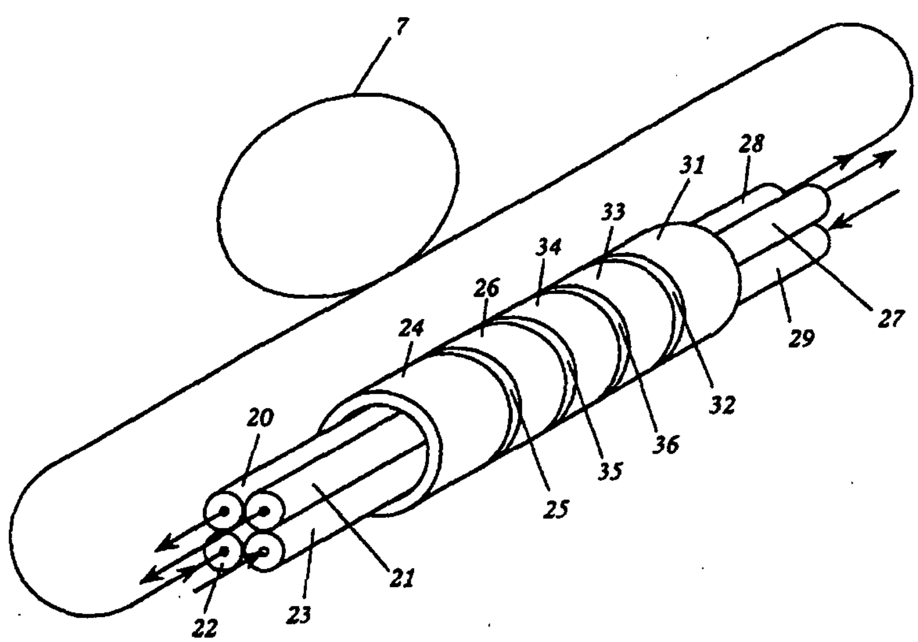
(54) Title: OPTICAL DEVICES INCLUDING OPTICAL ISOLATORS




(57) Abstract

An optical amplifier uses a single isolator (34) to perform both an input and an output optical isolating function by the use of a pair of graded index collimating lenses (26, 33) and two square arrays of four fibres (20, 21, 22, 23 and 27, 28, 29 and 30) arranged such that the signal passes twice through the isolator in collimated beams that are inclined to each other.

# OPTICAL DEVICES INCLUDING OPTICAL ISOLATORS

For a number of applications optical devices need to incorporate optical isolators, and not infrequently an individual example of such a device may employ more than one isolator. Such isolators may contribute significantly in the total cost of such optical devices, and so an appreciable saving in cost may be obtained by reducing the number of isolators required in any given optical device. The present invention is directed to the obtaining of such a reduction.

According to the present invention there is provided an optical device having a first optical waveguide optically coupled with a second optical waveguide along an optical path which path is characterised in that it passes at least twice in different pathways through an optical isolator from an input end thereof to an output end thereof.

Preferably, the different pathways are different pathways through the series combination of first and second lenses located on either side of the isolator and, having regard to the relatively limited acceptance angle of such isolators, it is generally preferred for the light passing through the isolator to be passing through it in collimated pathways.

By employing collimating lenses with planar end faces, such as graded index collimating lenses, reflection at those planar end faces adjacent the isolator can conveniently be employed to provide optical coupling to additional waveguides employed for instance for signal tapping purposes or, if a dichroic filter is employed at such an end face, for wavelength multiplexing purposes.

Th re follows a description of optical amplifiers incorporating optical devices embodying the invention in preferred forms. The description refers to the accompanying drawings in which:-

Figure 1 is a block diagram of an amplifier;

Figure 2 is a schematic side view of the elements of the amplifier of Figure 1 excluding its amplifier fibre, its optical pump and its two monitor photodiodes;

Figure 3 is a schematic perspective view of the elements of Figure 2, but additionally including a schematic representation of the amplifying fibre;

Figure 4 is a block diagram of an alternative amplifier; and

Figure 5 is a schematic representation of components of the amplifier of Figure 4 assembled upon a substrate in a housing.

Referring in the first instance to Figure 1, the basic elements of this optical amplifier comprise a signal input 1, a first tap coupler 2 for tapping off a small proportion of the input signal for feeding to an input signal power monitor photodiode 3, an input isolator 4, a laser pump source 5, a signal/pump wavelength multiplexing coupler 6, a length of amplifying fibre 7, a second tap coupler 8 for tapping off a small proportion of the amplified signal for feeding to an output signal power monitor photodiode 9, an output isolator 10, and a signal output 11. In this Figure 1 the input and output isolators are represented as entirely separate integers, though in the actual physical implementation, different optical paths through the same single isolator function respectively as the input and output isolators.

Referring now more particularly to Figures 2 and 3, a first assembly comprises a first set of four stripped optical fibres, typically single mode fibres, 20 , 21, 22 and 23 mounted in square array within the base of first length 24 of close-fitting glass capillary tubing. These four fibres are optically coupled with light-cure resin 25 to a collimating graded index lens 26. If necessary, individual fibres may be adjusted longitudinally to terminate at different distances from the adjoining graded index lens in order to take account of the effects of chromatic aberration and

magnification ratio. Similarly, a second assembly comprises a second set of four stripped fibres 26, 27 28, 29 and 30 mounted in square array within the bore of a second length 31 of close-fitting glass capillary tubing, these fibres being coupled with resin 32 to a second collimating graded index lens 33. The two assemblies are mounted on opposite sides of a polarisation insensitive optical isolator 34. Between the isolator 34 and the two assemblies are interfacial layers 35 and 36. Interfacial layer 35, which may be an air-gap layer, is provided to produce a refractive index change boundary providing Fresnel partial reflection, while interfacial layer 36 is a dichroic interference filter designed to be transmissive to light at the or each signal wavelength to be optically amplified by the amplifier, and to be reflective of light at the optical pump wavelength.

The relative alignment of the two assemblies is such that when the signal to be amplified applied to terminal 1 is applied to fibre 23 of the first assembly, a small fraction of the light is reflected in the face of graded index collimating lens 26 that is adjacent isolator 34 to emerge by way of fibre 20, from where it is fed to signal input monitor or photodiode 3. Most of the rest of the light is launched through the isolator 34 at a small angle to its axis, through the dichroic filter 36, and through the graded index collimating lens 33 of the second assembly which launches it into fibre 28. Light from the optical pump source 5 is coupled into fibre 29 of the second assembly, from where it is launched into graded index collimating lens 33. This light is reflected by the dichroic filter, and so makes a second passage through the lens, thereby becoming multiplexed with the signal power for launching into fibre 28. Fibre 28 is connected to fibre 22 by way of the amplifying fibre 7. In this way the amplified signal input is launched into the first assembly by way of fibre 22. A small portion of this light is similarly reflected in the face of graded index collimating lens 26 that is adjacent to the isolator 34 to emerge by way of fibre 21, from where it is fed to signal output monitor photodiode 9. Most of the rest of the amplified signal is launched through the isolator 34 for a second time along another inclined path, different from the first. From there it passes through the dichroic filter 35 and into

grad d index collimating lens 33 which launches it into fibre 27 which forms the amplified signal output 11 of the fibre.

It may be noticed that fibre 30 has no optical function in this amplifier, and so its mechanical function of helping to locate the positions of the other three fibres of the second assembly, fibres 27, 28 and 29, may be taken by a dummy fibre.

It will be evident in the two assemblies the four fibres could have been arranged side-by-side in the linear array instead of a square array. Such a linear array may be particularly preferred if the structure is being implemented in a format using integrated optics waveguides in place of optical fibres. In such an instance the waveguides can be arranged at their required spacings without having to have any recourse to the use of a dummy waveguide.

The particular amplifier described above with specific reference to Figures 2 and 3 employs collimating lenses 26 and 33 that are common to both the first passage of light through the isolator 34, that from fibre 23 to fibre 28, and to the second oassage, that from fibre 22 to fibre 27. However, it is to be understood that it is not necessary for the different passages of light through the isolator to employ the same pair of lenses, and in Figures 4 and 5 there is illustrated an example of an optical amplifier in which this is not the case. Figure 4 respresents, in diagrammatic form, the interconnection of the basic components of this amplifier. These comprise a length 40 of optically amplifying fibre; an optical source 41 acting as an optical pump for the amplifying fibre; and optical multiplexer 42 for combining the optical pump power from the pump source with an input signal applied to the amplifier at input port 43a; an optical isolator 44; two taps 45, 46 for tapping off a small proportion of the signal power respectively before and after amplification; a pair of monitor photodiodes 47, 48 positioned for receiving the tapped power; an output port 43b; and a form of feedback control system 49 that employs the outputs of the two monitor photodiodes 47, 48 for regultating the power output oif the pump source 41, and hence the gain provided by the amplifier. Although isolator 44 is physically only a single

isolator, the isolation that it provides is improved by causing it to function in effect as two isolators 44a, 44b optically in tandem by virtue of causing the light to pass through it not once, but twice. Referring now to Figure 5, all those components of the amplifier, with the exception of the amplifying fibre 40 and the feedback control system 49, are mounted in a housing 50 and, with the exception of the input and output ports 43a, 43b and isolator 44, all of these are mounted on a single crystal silicon motherboard 51 mounted within the housing 50. Through the housing wall are mounted four optical fibre hermetic feed-throughs 52a to 52d, each of which is threaded by an associated fibre pigtail 53, one end of which is secured to an associated silicon fibre platform 14a to 14d positioned in close proximity to an associated spherical microlens 54a to 54d. Also threading the wall of the housing 50 are electrical feed-through electrical terminals 55 to which internal electrical connection is made by way of flying leads 56. The isolator 44 is secured to the base of the housing 50 accommodated within a slot 57 formed in the motherboard. Precision optical coupling between each fibre pigtail and its associated spherical microlens is effected with the aid of its associated silicon platform to which the end of the fibre pigtail is secured. The motherboard 51 and silicon platforms 14a to 14d are crystallographically etched to provide complementary mating profiles with a clearance of less than 10 µm when the required alignment is established. While that alignment is maintained, resin (not shown) is introduced between the motherboard and the platforms, and is cured. The minimal thickness of the cured resin minimises misalignments caused by resin shrinkage. For further details of this alignment procedure reference may be made to application No. 94 17975.1.

Light launched into the housing 50 by way of the fibre pigtail 53 threading feed-through 52a, which constitutes the input terminal 43a of Figure 4 of the amplifier, is formed into a collimated expanded beam 58a by ball lens 54a. A small part of the light in this expanded beam 58a is reflected by a parallel-sided transparent plate, which constitutes the input signal power tap 45, and is directed on to the photosensitive surface of monitor photodiode 47. The remainder of the light is transmitted through a second parallel-sided transparent plate, which is provided on one

major surface with a dichroic filter to constitute the optical multiplexer 42 that operates by being highly reflective to light at the pump wavelength incident upon it from the pump laser 41 while being substantially transparent to light at the signal wavelength incident upon it from ball lens 54a. The output of the pump laser 41 is formed into a collimated expanded beam 58b which is superimposed on expanded beam 58a. These two expanded beams are then focused by ball lens 54b on to the inboard end of the fibre pigtail 53 that threads feed-through 52b. One end of the optically amplifying fibre 40 is optically coupled with the fibre pigtail threading feed-through 52b, while the other end is similarly optically coupled with the fibre pigtail threading feed-through 52c. The amplified input signal is then directed from the fibre pigtail threading feed-through 52c into ball lens 54c to produce a collimated expanded beam 58c. This is transmitted through the isolator 44, after which a small proportion is reflected by a third parallel-sided transparent plate, which constitutes the output signal power tap 46, and is directed on to the photosensitive surface of monitor photodiode 48. The remainder of the light of expanded beam 58c is transmitted through the output signal power tap 46 to be incident upon ball lens 54d which focuses the light on to one end of a length 60 of single mode fibre that loops it back to be launched through ball lens 54e for a second time through isolator 44, this time in expanded beam 58d. Once again a small proportion is directed on to the photosensitive surface of monitor photodiode 48 by power tap 46, while the remainder is transmitted to be incident upon ball lens 54f which focuses the light on to the inboard end of the fibre pigtail 53 that threads feed-through 52d, the output of the amplifier.

**CLAIMS**

1. An optical device having a first optical waveguide (23) optically coupled with a second optical waveguide (27) along an optical path which path is characterised in that it passes at least twice in different pathways through an optical isolator (34) from an input end thereof to an output end thereof.

2. An optical device as claimed in claim 1, wherein said different pathways are different pathways through the series combination of first and second lenses (26, 33)located on either end of the optical isolator.

3. An optical device as claimed in claim 2, wherein the first and second lenses are collimating lenses in spaced axial alignment on either end of the optical isolator.

4. An optical device as claimed in claim 3, wherein the first collimating lens has a planar face facing the isolator.

5. An optical device as claimed in claim 4, wherein the first optical waveguide is additionally optically coupled with a third optical waveguide (20) by reflection in the said planar face of the first collimating lens.

6. An optical device as claimed in claim 3, 4 or 5, wherein the second collimating lens has a planar face facing the isolator.

7. An optical device as claimed in any preceding claim, wherein said optical path includes a length of optically amplifying optical waveguide (7) between one of its passings through the isolator and another.

8. An optical device as claimed in claim 7, wherein said different pathways are different pathways through the series combination of first and second collimating lenses in spaced axial alingment on either end of the isolator, and wherein the second collimating lens has a planar face

facing the isolator and a first end of the amplifying waveguide is additionally optically coupled with a fourth optical waveguide (29) by reflection in said planar face of the second collimating lens.

9. An optical device as claimed in claim 8 wherein the reflection at said planar face is a reflection at a dichroic filter (36).

10. An optical device as claimed in claim 8 or 9, wherein the first collimating lens has a planar face facing the isolator and a second end of the amplifying waveguide is additionally optically coupled with a fifth optical waveguide (21) by reflection in said planar face of the first collimating lens.

11. An optical amplifier including an optical device as claimed in claim 5, wherein said optical path makes two passages through the isolator and includes a length of optically amplifying optical waveguide (7) between the two passings, wherein the second collimating lens has a planar face facing the isolator, wherein one end of the amplifying waveguide is additionally optically coupled with a fourth optical waveguide (29) by reflection in said planar face of the second collimating lens at a dichroic filter (36) which exhibits high reflectivity at the emission wavelength of an optical pump source optically coupled with the fourth waveguide and exhibits low reflectivity at a signal wavelength amplified by the amplifying waveguide, and wherein the other end of the amplifying waveguide is additionally optically coupled with a fifth optical waveguide (21) by reflection in said planar face of the first collimating lens.

12. An optical amplifier as claimed in claim 11, wherein said other end of the amplifying waveguide is arranged with an end of each of the first, third and fifth waveguides in a square array adjacent the face of the first collimating lens that is optically remote from the isolator, and wherein said one end of the amplifying waveguide is arranged with an end of each of the second and fourth waveguides and an end of a spacer element in a square array adjacent the face of the second collimating lens that is optically remote from the isolator.

12 An optical amplifier as claimed in claim 11, wherein said other end of the amplifying waveguide is arranged with an end of each of the first, third and fifth waveguides in a linear array adjacent the face of the first collimating lens that is optically remote from the isolator, and wherein said one end of the amplifying waveguide is arranged with an end of each of the second and fourth waveguides in a linear array adjacent the face of the second collimating lens that is optically remote from the isolator.

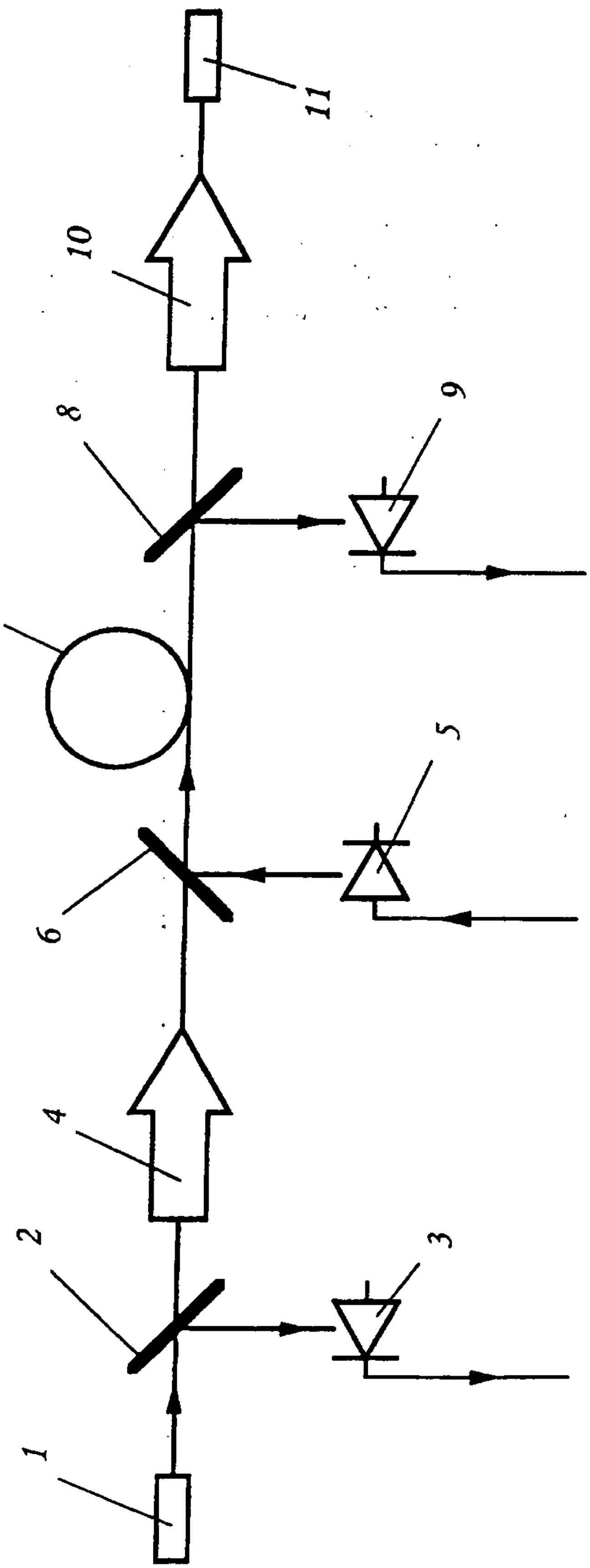



Fig. 1.

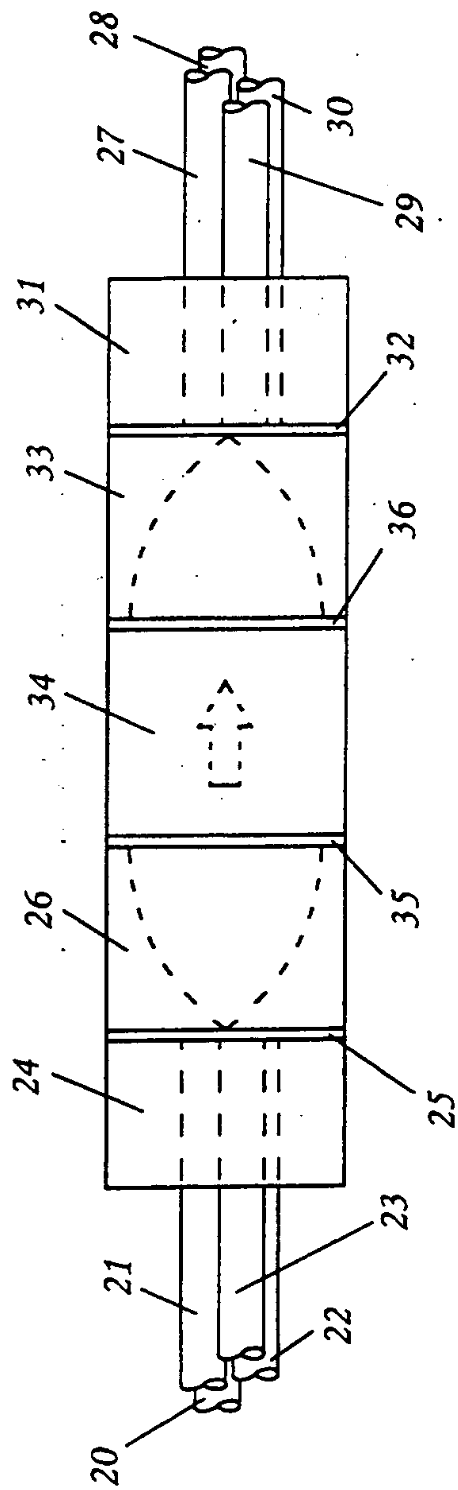



Fig. 2.

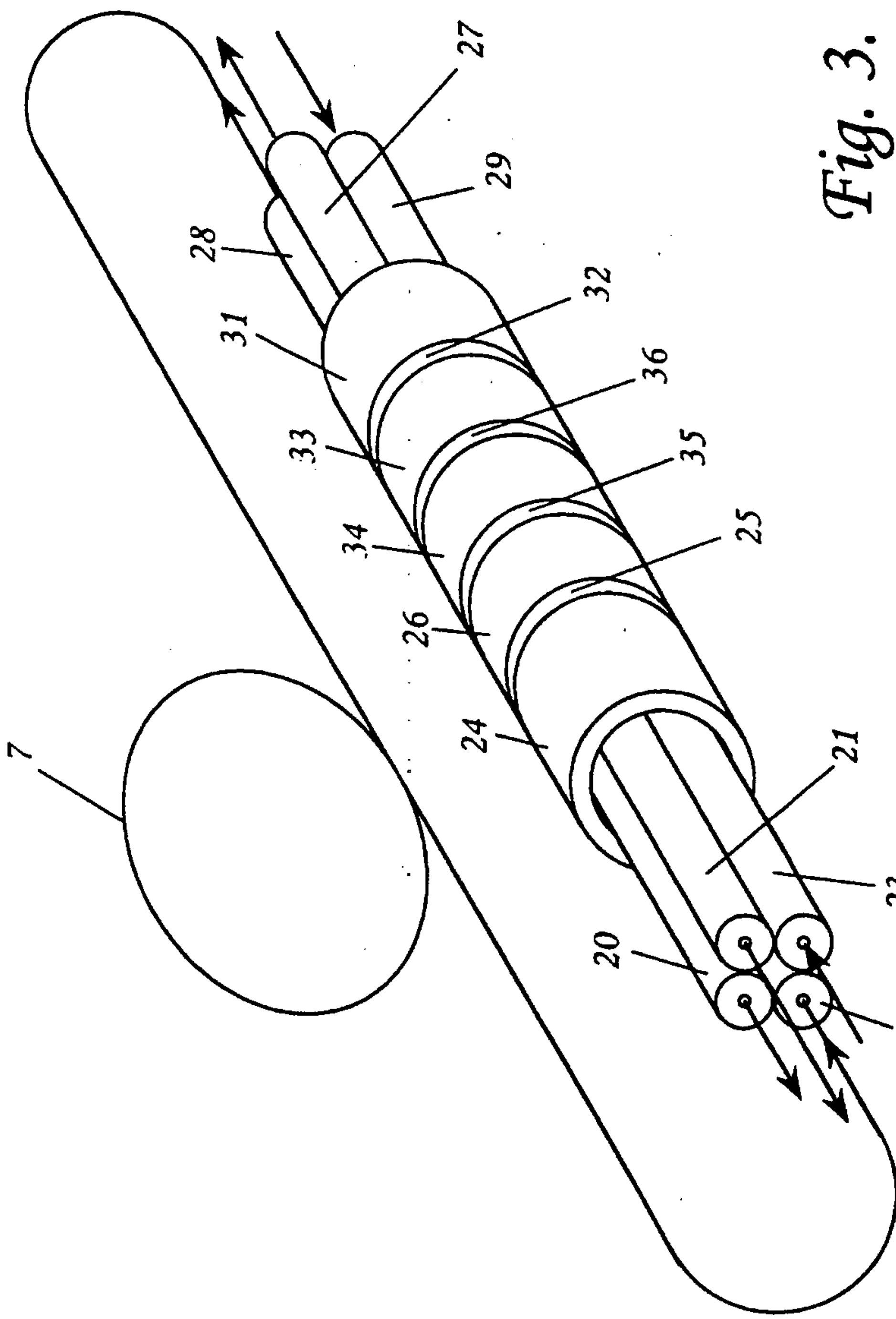



Fig. 3.

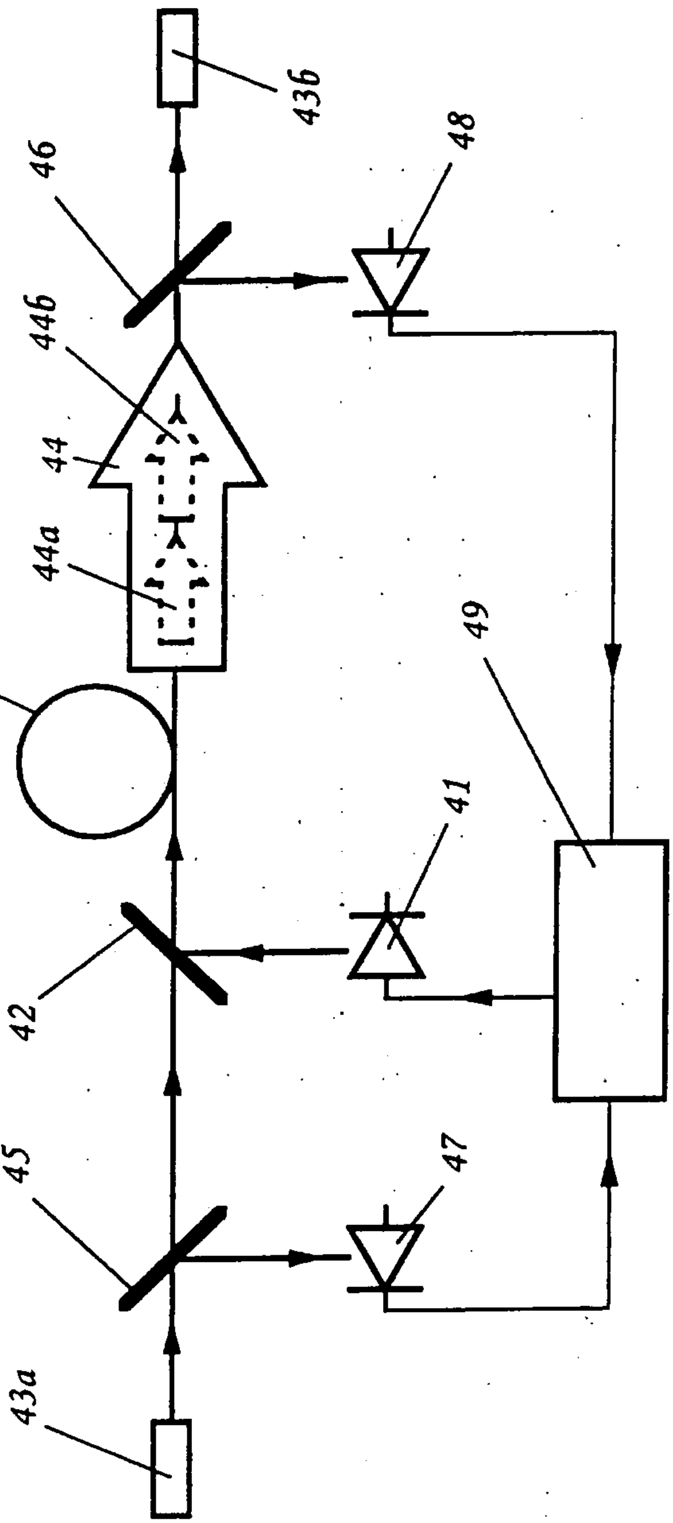



Fig. 4.

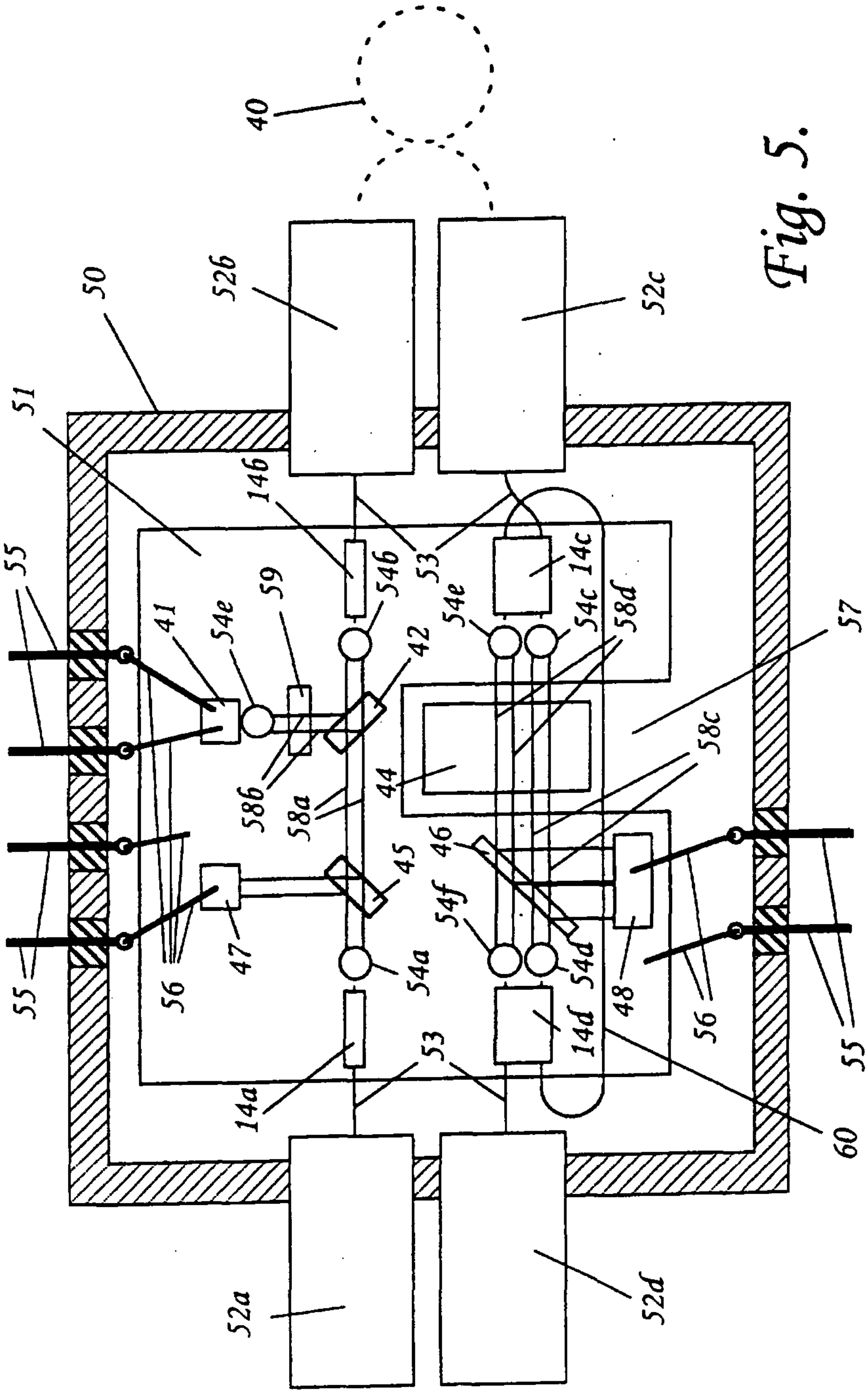

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Fig. 5.

# INTERNATI NAL SEARCH REPORT

Inten ıal Application No
PCT/GB 95/02442

**A. CLASSIFICATION OF SUBJECT MATTER**
IPC 6 G02F1/09 H01S3/06 G02B6/26

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G02F H01S G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

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|---|---|---|
| X | WO,A,93 02373 (KAPTRON INC) 4 February 1993<br>see page 9, line 32 - line 38<br>see page 10 - page 15<br>see page 16, line 1 - line 17<br>see figures 1-7<br>--- | 1-4,7,9,<br>11,13 |
| X | EP,A,0 404 052 (FUJITSU LTD) 27 December 1990<br>see column 6, line 33 - line 58<br>see column 6 - column 7<br>see column 10, line 24 - line 39<br>see figures 1-7<br>---<br>-/-- | 1,13 |

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search
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Intern al Application No
PCT/GB 95/02442

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

| Category * | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
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